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Solar Powered Atmospheric Water Generator and overview on AWG technologies

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ABSTRACT: In many countries, it is difficult to obtain water for drinking, irrigation or other purposes, and especially so in the arid regions and with regions or locations where there is no electricity or fuel sources. The problem of water scarcity is also prevalent in many places around the world due to lack of rainfall. In highly humid areas such as places close to the sea, water can be obtained by condensing the water vapour present in the air. Solar-powered Atmospheric Water Generator is an appliance that employs dehumidification/condensing technology, that extracts water present in the air in the form of vapour by applying Peltier effect of Thermo-Electric Cooling. The system consists of cooling elements, heat exchanger and air circulation unit. A Solar PV unit with adequate current output drives the cooling elements through a controlling circuit. This concept has promising application in this age of technology when renewable energy is poised to grow rapidly. Sun-To-Water and use of MOFs are latest developments in Atmospheric Water Generator sector. Experiments have shown that Solar-energy based AWG are able to produce around 24L of water per day without the use of moving parts, no chlorofluorocarbons use and no consumption of electricity. This paper presents an overview of the AWG technologies and in particular Solar based AWG using Peltier effect.

KEYWORDS: Atmospheric Water Generator, Peltier Effect, Thermo-electric Cooling, Solar Energy, Water Condensation.

ABBREVIATIONS:

AWG – Atmospheric Water Generator

MOF –Metal Organic Framework

TEC – Thermo-Electric Cooler

I. INTRODUCTION

Life, both animals and plants, is impossible without water. Dehydration can result in death, as about 70% of the human body is water. Of the total surface of the earth, 75% is water, and just below the surface, ground-water can also be found in many locations. If there is no water, there will be no life. As Herodotus said, Egypt is the "Gift of the Nile", and it reminds us that historically it was water that determined the location of human settlements. The atmosphere contains a large amount of water in the form of moisture. This water, in common terminology, is expressed as % Relative Humidity or RH. For example, when we say 60% Humidity at 20°C, one cubic meter of air will contain about 10gms of water. This water in the atmospheric air can be extracted by implementing a device like Atmospheric Water Generator operating and can effectively use Solar Energy.

Various ways of producing potable water have been developed. Some conventional technologies are well developed and some innovative and environmental friendly technologies are being investigated. A conventional-cooling

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condensation-type AWG applies the vapour compression refrigeration cycle with a fan which moves the filtered air over the evaporator coil. The temperature of the air is lowered below its dew point and the water vapour in the air condenses (Wahlgren, 2001). These type of AWGs produce drinking quality water and require electricity.

In the past few years, some projects have been done to establish the concept of air-condensation as well as generation of water with the help of Peltier devices, such as harvesting water for young trees using Peltier plates that are powered by photovoltaic solar energy, etc. The Peltier module is a thermo-electric device which cools the atmospheric-air below its dew-point and thereby condensing the water vapour present in the air. In Peltier effect, this is achieved with the help of an electronic device called a Thermo-electric Peltier couple, which is power by a Solar Cell.

Latest advancements in AWG technology include Sun-To-Water devices and Atmospheric Water Generator using MOFs (Metal Organic Framework). In Sun-To-Water device, air is pulled into the unit using energy efficient fans, which is circulated through desiccant technology which absorbs water molecules. During extraction phase, water is extracted from the desiccant using warm air and condensed into pure, clean water. Minerals are added into the water and can be piped directly into homes, garden, or external water tank. In MOF-based technology, water vapour from the air is absorbed at night, and solar heat is used to release it as liquid water during the day producing, as per one estimate, approx. 2.8L of waters per day for every kilogram of MOF used.

II. RELATED WORK

The conventional Atmospheric Water Generator works on the principle of cooling and condensation of water vapour. “Vapour Compression Refrigeration System Generating Fresh Water from Humidity in the Air” states that dehumidifying unit using vapour compression refrigeration system is more effective than the Peltier system but then it consumes electricity, has moving parts, is not portable, its initial as well as operation and maintenance cost is high, and is noisy in operation. From the paper “Water generator water from air using a liquid desiccant method” the author is trying to propose that even though dehumidification by a liquid desiccant method is new and possess a lot of potential theoretically, but when the researchers made a prototype and tested it, the results were not satisfactory. The device could produce only 72.1mL of water per kW-hr.

“Solar powered automated atmospheric water generator using Peltier device” paper concludes that dehumidification unit using Peltier device is portable and environmentally friendly. It has a simple design and has high endurance capability. This type of Atmospheric Water Generator can be quite useful in extreme situations like during floods or in desert and rural areas. It has great advantages as it works like a renewable source of atmosphere water and doesn't need a heavy power source. Applying this system to a highly humid region, as much as 1L of condensed water can be produced per hour during the daylight, which is a promising result.

III. CONVENTIONAL TECHNIQUE AND WORKING PRINCIPLE

Traditional refrigeration cycle of dehumidification remains the most widely used method for generating water from atmospheric humidity. This method circulates air over cooling coils connected in a refrigeration cycle to bring the water in the air below its dew point. The dew point of the water is dependent on the vapour pressure and humidity conditions.

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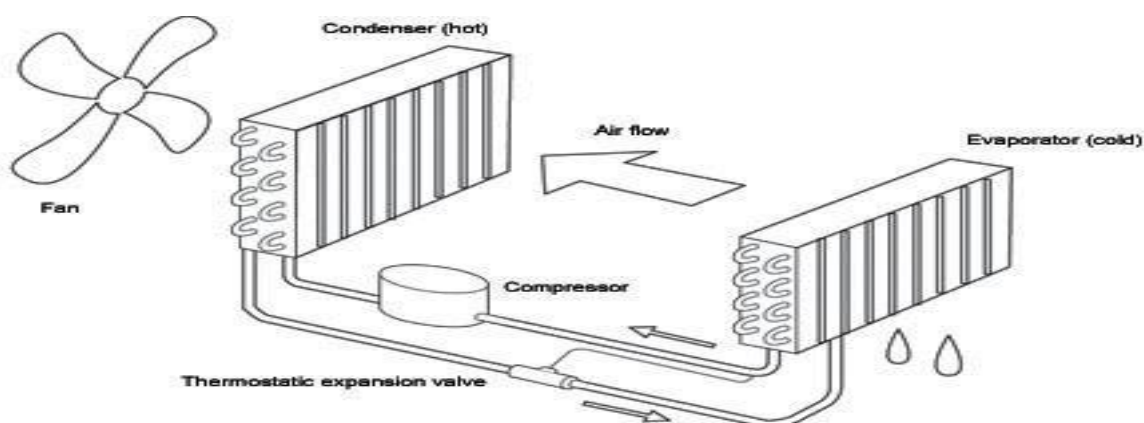


Fig. 1: Dehumidification by Refrigeration

To reach the dew point the air running through the unit will have to be cooled by a considerable amount. This process requires a constant energy supply. This approach is expressed below:

Operation:

In a conventional AWG, a compressor circulates refrigerant through a condenser and then an evaporator coil which cools the air surrounding it.

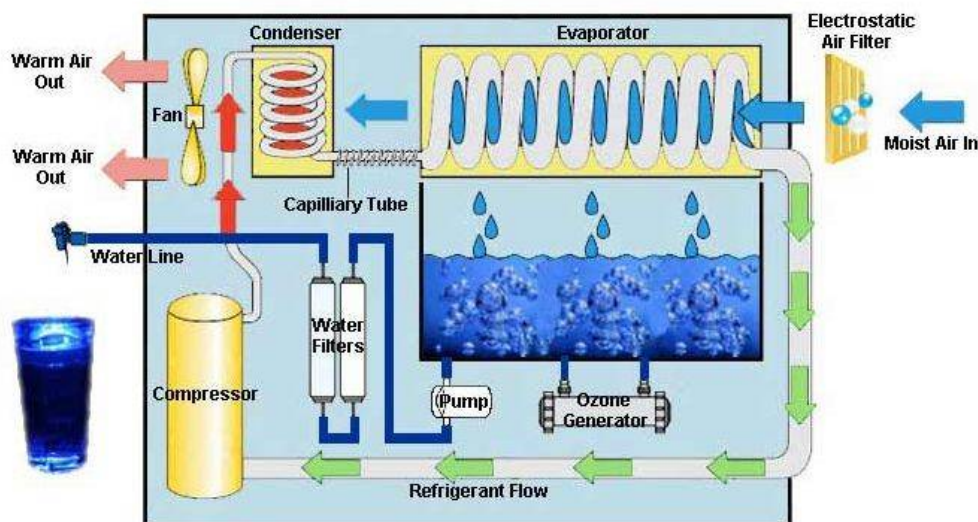


Fig. 2: Conventional Atmospheric Water Generator

It leads to lowering the air temperature to its dew point, causing water to condense. A controlled-speed fan pushes filtered air over the coil. Then water is passed into a holding tank with purification and filtration system to help keep the water pure.

The water production rate depends on relative humidity, ambient air temperature and the size of the compressor. Atmospheric water generators become more effective as relative humidity and air temperature increase. The cooling condensation atmospheric water generators do not work efficiently when the temperature falls below 18.3°C (65°F) or

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the relative humidity drops below 30%. The principle of this type of AWG can be understood by the fact that water is often seen condensing and draining out from the home air conditioners when the ambient air is humid and hot. The economical AWG depends on the capacity of the machine, local humidity, temperature conditions and the cost to power the unit.

IV. LATEST TECHNIQUE AND WORKING PRINCIPLE

1. Atmospheric Water Generator with Peltier effect.

Atmospheric water generator works on the principle of Peltier effect. So, what is Peltier effect and how does it work in atmospheric water generator?

Peltier effect is the cooling of one junction and the heating of the other when an electric current is maintained in a circuit of materials consisting of two dissimilar conductors; the effect is stronger in circuits using dissimilar semiconductors. In a circuit consisting of a battery joined by two pieces of copper wire to a length of bismuth wire, a temperature rises at the junction where the current passes from copper to bismuth and a temperature drops at the junction where the current passes from bismuth to copper. This effect was discovered by the French physicist Jean-Charles-Athanase Peltier in 1834.

Peltier Couple and its working feature:

In AWG, Peltier couple is used as a thermo-electric device. It has two sides (a p-type and an n-type semiconductor), and when DC current flows through the device, one side becomes cooler while another side gets hotter. Peltier Cooler or Thermo-Electric Cooler (TEC) consists of a Peltier element and a powerful heat-sink/fan combination. Peltier elements come in various forms and shapes. Typically, they consist of a larger amount of thermocouples arranged in rectangular form and packaged between two thin ceramic plates. This type of device is so powerful that it can freeze water within minutes. A TEC also has some analogous parts. Energy (heat) is absorbed by electrons at the cold junction, as they pass from a low energy level in the p-type semiconductor element to a higher energy level in the n-type semiconductor element. It is the power supply that provides the energy to make those electrons to move through the system. At the hot junction, energy is expelled to a heat sink as electrons move from a high energy level element (n-type) to a lower energy level element (p-type).

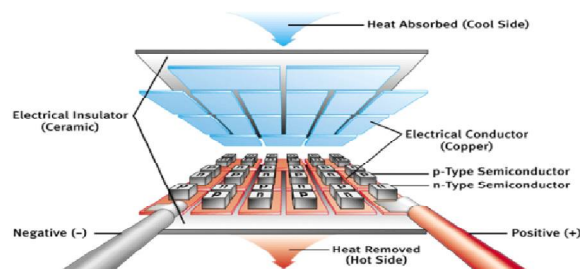


Fig. 3: Peltier Device

Practically, TE couples are combined in a module, connected electrically in series and thermally in parallel to obtain a promising output. But it will be inconvenient to use such a device that has less advantageous work done to power ratio. There are modules available in the market according to variety of sizes, shapes, operating voltages-currents and ranges of heat pumping capacity. The present trend, however, is towards a larger number of couples operating at lower currents; before choosing an efficient device, some parameters must be determined. These are:

T_c : Temperature at Cold Surface.

T_h : Temperature at Hot Surface.

(T_h incorporates two major parameters:

1. The efficiency of the device i.e. between the hot surface of the TEC and the ambient environment.
2. The temperature of ambient environment into which the heat is being rejected.)

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Q_c: The heat to be absorbed at the Cold Surface.

The object to be cooled is confined with the cold surface of TEC, thus the temperature of that object starts falling until it approaches the temperature of the cold surface of the TEC.

ΔT , an important parameter, is defined as:

$$\Delta T = T_H - T_C$$

This difference should be accurately determined/specified if the design is to operate as desired.

Operation:

According to the previous elaboration, the objective is to calculate the dew point temperature T_{dp} from the gathered information about the ambient environment in which the device is going to run. Once the dew point temperature is obtained, the Peltier coefficient (ratio of the rate at which heat is evolved or absorbed at a junction of two metals in the Peltier effect to the current passing thru the junction) and the current rating of the TEC can also be obtained. As soon as the device is powered the hot side starts getting hotter and cold side cooler; reaching the dew point temperature. The cooler side of TEC starts to cool the air passing through it and the water vapours start to condense. It is important to keep in mind that when TEC starts it takes a longer time to actually produce water, though it reaches the dew point temperature readily, after some time the process stabilizes to produce sufficient water according to the experimental results of this project.

The solar cell unit installed in this project was rated as output of 12 V with the maximum output power of 120 W, which is able to supply enough power to keep running three 40 W (3.5 A) Peltier coolers (TEC) connected in parallel. The Peltier device has a dimension of 4x4x0.8 cm. The maximum temperature difference i.e. ΔT of 87°C. A 3000rpm, 15x15cm (size of TEC) fan that is capable of producing airflow of max 500cfm is used for circulation of the air. The heat sinks are made of aluminium and anodized. Activated carbon filter are used for water filtration. Two temperature sensors and a microcontroller used for temperature control.

Air capacity of holding water-vapour varies according to the temperature of the air and humidity. The warmer the air, the more water-vapour it can hold. The moist air is pumped first into the tube thus the cold side of the Peltier element helps to decrease the air temperature. So, as the air cools down, its capacity of holding water decreases and water moisture starts condensing. The air is then passed through to take away the heat from the hotter side of TEC, acting as a heat sink as shown in the diagram. The condensed water falls into a reservoir then passes through a filter. As per the experimenters, this system was able to produce about 1L of water per hour in high humidity conditions.

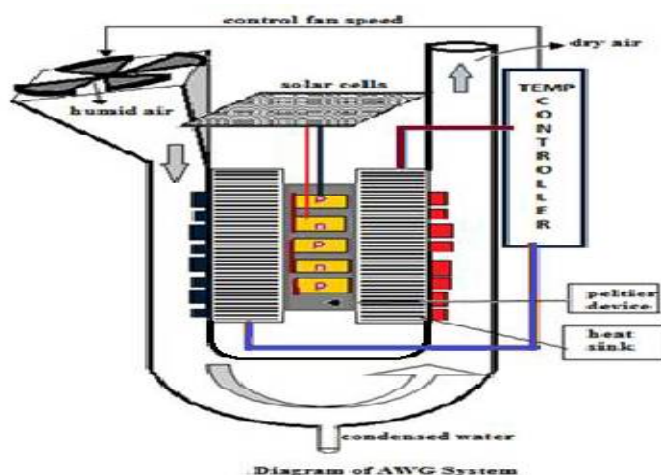


Fig. 4: AWG with Peltier effect powered by Solar energy.

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Advantages of TEC over conventional device:

Some key advantages of Solar Powered TEC over the conventional refrigeration system are listed below:

1. No electricity consumption, only Solar-energy is utilized.
2. No moving parts, so less maintenance.
3. No use of chlorofluorocarbons (CFCs) like in conventional systems, hence more environmental-friendly.
4. Better temperature control can be maintained.
5. Can be more effectively used in smaller size applications or more severe environments than conventional refrigeration.
6. Has a long life, with mean time between failures (MTBF) exceeding almost 100,000 hours.
7. Controllable via changing the input voltage/current very easily.
8. Draws comparatively lower current than a conventional compressor based refrigeration system.

1. Sun-To-Water Device using desiccant technology.

An introduction to desiccants:

Desiccants are the substances that absorb water-vapour molecules from the air via an adsorptive process. Adsorption refers to a desiccant that does not change phase as it collects airborne moisture. Most adsorbents are solids for example activated alumina, silica gel, and zeolites (molecular sieves), etc.

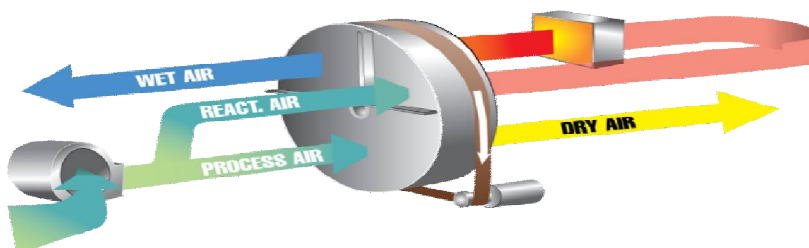


Fig. 5: Desiccant Dehumidification

Operation:

Sun-To-Water device works in three stages: Absorption, Extraction and Remineralization. Air is pulled into the unit using energy efficient fans, and circulated through the desiccant. The device uses a combination of salt based desiccant, fans, solar heat, and a condenser, and requires both a solar thermal input and an electric input.

The process starts with an exterior unit that is about the size of an air conditioner. The first step is absorption: small, energy efficient fans pull humid air into the unit. The air passes over a salt-based desiccant that absorbs water molecules like a sponge. The desiccant absorbs only H₂O from the air, leaving aside contaminants.

During the second phase, the extraction, water is extracted out from the desiccant with the use of warm air, passed thru the condenser and the condensed water is collected. The last step, remineralization, adds minerals back into the water. Water can then be directly used in homes, garden, or external water tanks. This system can be fully powered using Sun Energy, i.e. Solar PV to supply electricity to run the fans and Solar Collector to supply warm air.

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The quality of the water produced - even when created from smog-polluted air - can meet World Health Organization's standards for drinking water. Desert climates are not an obstacle since the system uses salt as desiccant instead of Freon to capture and condense humidity into water. Also, if the unit is in a desert climate, the fans can be designed to move faster to pull more air. Multiple units can be stacked for more water generation capacity for larger homes or businesses. These unit scan produce 40-100 gallons of clean water per day and can be powered by solar or solar plus grid power.

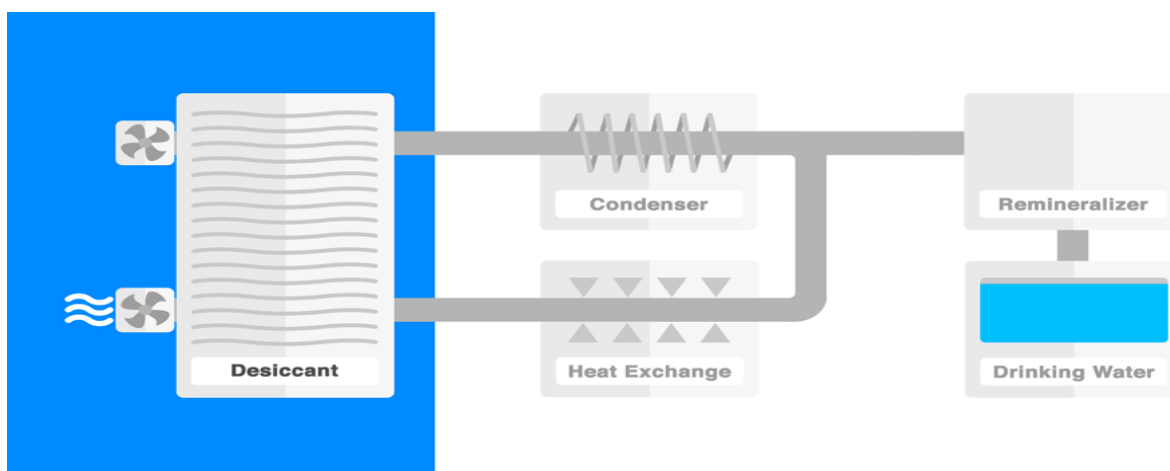


Fig. 6: Sun-To-Water working principle

2. Solar powered Atmospheric Water Generator using MOFs.

What is MOF and how it is useful in AWG device?

Metal Organic Frameworks are compounds consisting of metal ions coordinated to organic ligands to form up to 3dimensional structures. In some cases, the pores are stable during elimination of the guest molecules (often solvents) and could be refilled with other compounds. Because of this property, MOFs are able to be used as storage of gases such as hydrogen and carbon dioxide. Other possible applications of MOFs are in gas purification, in gas separation, in catalysis, as sensors and as supercapacitors.

Researcher's team led by Omar Yaghi, a chemist at the University of California, developed the first MOFs - porous crystals that form continuous 3D networks - more than 20 years ago. The networks assemble in a Tinkertoy-like fashion from metal atoms that act as the hubs and sticklike organic compounds that link the hubs together. By choosing different metals and organics, chemists can dial in the properties of each MOF, controlling what gases bind to them, and how strongly they hold on. In 2014, Yaghi and his colleagues synthesized a MOF with ability to absorb water, even under low-humidity conditions. Then with the help of Evelyn Wang, a mechanical engineer at the Massachusetts Institute of Technology (MIT) in Cambridge, he decided to use MOFs for water generation through the atmosphere. They synthesized the new zirconium-based MOF (MOF-801), and use it in water harvesting device.

Operation:

Designed system of Wang and her student's uses a kilogram of dust-sized MOF crystals which are pressed into a thin sheet of porous copper metal. MOF's sheet is installed between a solar absorber and a condenser plate and they are positioned inside a chamber. During night period the chamber is opened, where ambient air goes through the porous MOF and water molecules get stuck to its interior surfaces.

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In the morning, the chamber is closed, and sunlight falls on the solar absorber on top of the device which heats up the MOF, due to which it liberates the water droplets as vapour. The temperature difference, as well as the high humidity inside the chamber, causes the vapour to condense as liquid water, which drips into a collector. The experimental setup was able to collect 2.8L of water out of the air per day using 1 kilogram of MOF. The practical experimentation done by Wand and her students gives considerable proof of concept. There are plenty of opportunities for improvement as per researchers. In starting, zirconium costs \$150 a kilogram, making water-harvesting devices too expensive to be commercially viable at present.

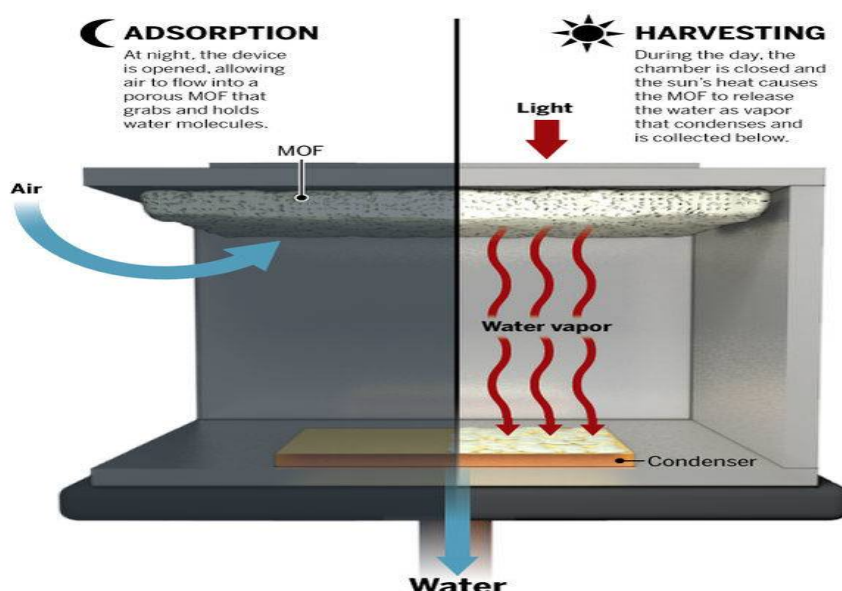


Fig. 7: Overview of working principle of AWG using MOFs.

However, as per Yaghi and team, they have already had early success in designing water-grabbing MOFs that replace zirconium with aluminium, a metal that is 100 times cheaper. That could make future water harvesters cheap enough not only to be used for drinking water in arid regions, but perhaps even supply water to farmers in the desert.

V. CONCLUSION

These devices surely stand aside in comparison to conventional ways of getting safe water with simple design and endurance capability. By applying devices other than conventional evaporating principle device, we can extract reasonable amount of water from atmosphere. Use of Solar Energy by way of Solar PV or Solar Heating, these devices can not only be energy efficient but also can be used as standalone systems where electricity or other forms of energy is not readily available. Design of devices is relatively simple and can be carried to places like hilly areas, arid regions, flood areas, etc. In the current climatic conditions with global warning threat and the water resources over the world diminishing, these solar integrated devices can be extremely useful. With the advances in technology of these devices leading to more enhanced & efficient systems, such AWG systems hold bright future for generation of the much needed water.

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